BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Redesign of the LM S-Band Steerable Antenna Mounting
Case 310

DATE: November 6, 1967

FROM: A. C. Merritt

ABSTRACT

The LM steerable S-Band antenna has been remounted to obtain a more desirable region of coverage within gimbal stop limits. This memorandum discusses both the reasons for the redesign and the corresponding redefinition of antenna tracking constraints. In particular, it is shown that the 180° pilot-yaw maneuver, which is planned for LM descent during the lunar landing mission, must be in the negative sense about the $+X_B$ axis, in order to avoid gimbal stop encounter. It is noted that remounting of the antenna has not altered the attitude constraints imposed by possible structural interference situations.

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MEMORANDUM FOR FILE

Introduction

During LM descent, it is planned that the DPS (Descent Propulsion System) braking maneuver will begin with the LM in a 180° pilot-yaw attitude, so that the forward windows are facing the lunar surface for viewing. Somewhat before radar acquisition (30,000 ft.), it will be necessary to re-orient the LM to a "face-out" attitude by yawing through 180°, in order that the radar antenna be properly positioned. The requirement to maintain continuous LM-earth communications during this 180° yaw maneuver motivated the antenna redesign discussed in this memorandum. Prior to redesign, gimbal-stop encounter precluded continuous communications (during the yaw maneuver) for some of the lunar landing sites under consideration.

Redesigned Configuration

Redesign of the LM S-Band steerable antenna mounting will now provide a more desirable region of coverage for the 180° yaw maneuver mentioned above.* Azimuth gimbal limits have been increased, as per the change authorization, from $\pm 75°$ to $\pm 90°$; in practice, the new limits will be $\pm 87°$. The azimuth axis of the antenna will now be inclined 45° to the LM $+X_B$ axis, in the sense of positive rotation about the $+Z_B$ axis. (Refer to Figure (1), attached.**) If the new and old antenna coordinates are designated (EL^1, AZ^1) and (EL, AZ) respectively,

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*As per Contract Change Authorization No. 632.

**The electronics assembly at the base of the antenna has also been remounted, but this is not relevant to the discussions of this memo, and is not indicated on Figure (1).

(NASA-CR-90262) REDESIGN OF THE LM S-BAND STEERABLE ANTENNA MOUNTING (Bellcomm, Inc.) 10 p

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then this redesign will result in the following transformations:

$$EL^1 = TAN^{-1}\left[\left(SIN(EL) + TAN(AZ)\right)\Big/\sqrt{2}\ COS(EL)\right]$$

$$AZ^1 = SIN^{-1}\left[\left(SIN(AZ) - COS(AZ)SIN(EL)\right)\Big/\sqrt{2}\right]$$

These transformations will redefine the antenna angles which correspond to a particular antenna pointing direction. An onboard computer routine is to be included in the LGC (LM Guidance Computer) to calculate the antenna gimbal angles required for earth acquisition. (Reference 1) The antenna routine cannot be called when the LM is executing a thrusting maneuver, so that it is important to establish a graphical or intuitive relationship between a direction vector relative to the LM and the corresponding antenna angles.

Redesign Significance

The significance of the antenna redesign is understood by a comparison of Figures (2) and (3), which show regions of structural interference and "yaw loci" for the old and new antenna designs, respectively, in the antenna's elevation-azimuth coordinate system. The convention for the order of rotations is elevation, then azimuth. The cross-hatched areas define antenna pointing conditions for which automatic earth-track would be either questionable or impossible, due to LM structural interference.* The families of solid curves are antenna angle locus plots for 360° rotation about the LM + X_B axis ("yawing"), with the antenna tracking so as to point in an inertially-fixed direction. Consider any point on any one of these locus curves. The point chosen corresponds to a particular direction in space. Fix the antenna pointing vector in this direction and yaw the LM through 360°. The antenna angles will then follow the locus

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*The problem of structural interference of LM-Earth communications during descent and ascent is discussed in Reference (2).

curve chosen, in the direction indicated by the arrows, for a positive right-handed rotation about the LM + X_B axis (top of LM). All curves are labelled with the constant angle that the antenna pointing vector would make with the LM + X_B axis.

In comparing Figures (2) and (3), one can see that prior to redesign, (Figure 2), gimbal stop encounter would occur during a 360° yaw (or even a 180° yaw) for any intital orientation that was greater than 75° from the $+X_B$ axis. As of the redesign (Figure 3), gimbal stop encounter during a 180° yaw will occur only for antenna orientations greater than 132° from the $+X_B$ axis. However, a 360° yaw is now possible only for initial orientations less than 42° from the $+X_B$ axis.

The dotted curve included on Figure (3) is a representative locus of antenna angles during LM descent to a landing site at an eastern lunar longitude, and illustrates the significance of the antenna redesign. The arrows indicate the direction of increasing time. At time t_1, the LM begins powered descent in a "face-down" attitude, and the antenna elevation decreases as pitch and range angles change. Somewhat before 30,000 ft., a yaw maneuver is initiated in order to re-orient the LM to a zero-yaw, "face-out" attitude for radar acquisition. On the example locus, the 180° yaw takes place between the points labelled t_2 and t_3, and for this example, the LM is artificially held static in position as well as pitch and pilot-roll attitude during this maneuver. At t_3, a zero-yaw, face-out attitude is reached and antenna tracking continues to time t_4 and beyond. For an actual pitch profile, the portion of the curve between t_2 and t_3 would be slightly different from that shown, and would depend on the particular trajectory as well as the chosen yaw rate.

Yaw Maneuver Constraints

There are several important things illustrated by the above example. First, if the yaw maneuver had been initiated somewhat before the point t_2, i.e., when the antenna pointing vector was within a cone of 48° half-angle about the LM - X_B axis, then there would have been a potential gimbal stop encounter situation for an actual pitch profile. This would correspond to yawing through 180° early in the descent trajectory, at an altitude above 30,000 feet. A second observation from the example is that the direction of the 180° yaw was of necessity a negative right-handed rotation about the LM + X_B axis. A positive rotation would have resulted in encounter of the +255° gimbal stop, as well as structural beam interference for a large number of t_2 conditions. Further, one may show that for all of the lunar landing sites now under consideration, the antenna elevation during early descent will be greater than + 90° for a face-down attitude, and less than + 90° for a face-out attitude. Therefore, the 180° yaw from face-down to face-out will correspond to moving from right to left on the plot of Figure (3).

On the basis of these observations, the following constraints can be established for programming the 180° yaw maneuver:

1. During LM descent, yaw from a face-down attitude to a face-out attitude must be in the sense of a negative rotation about the LM + X_B axis, in order to avoid both beam interference and the +255° elevation stop.

2. If the yaw maneuver is initiated late enough during LM descent that the antenna is not pointing within a cone of 48° half-angle about the $-X_B$ axis, then gimbal stop encounter cannot occur.

<u>Worst-Case Trajectory</u>

A typical nominal powered descent trajectory will put the LM at 30,000 ft. above the lunar surface at about 310 seconds after DPS (Descent Propulsion System) ignition. If one assumes that 30,000 ft. is the altitude at which radar acquisition will occur, then this is also the altitude at which a face-out attitude must be attained. If the onboard guidance has been programmed to perform a 180° yaw from face-down to face-out at a rate of 10°/sec.*, then the 180° yaw must be initiated at 292 seconds after DPS ignition. At 292 seconds, descent to a far eastern

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*Automatic attitude rotations using the LM PNGCS are limited to 10°/sec. during powered flight. Manually controlled rotations in the attitude-hold mode may be commanded up to 20°/sec.

site (viz., +45° longitude) could result in antenna angles of $(EL^1, AZ^1) = (211°, 30°)$ for the new design, for worst-case trajectory conditions. For a nominal pitch profile, even this worst-case example would not result in encounter of the +255° elevation stop.

Summary

Although it has been shown that the LM S-Band steerable antenna need not experience gimbal stop encounter even for worst-case conditions, the fact that potential gimbal stop encounter has not been entirely eliminated by redesign suggests that it will be desirable to analyze gimbal stop situations for off-nominal cases (e.g., 180° yaw early in the descent trajectory). Onboard programming of the 180° yaw maneuver should observe the constraints given, in order to assure that gimbal stop be avoided. In addition, it should be noted that remounting of the antenna has not altered the attitude constraints imposed by possible structural signal-interference situations.

A. C. Merritt

2013-ACM-srb A. C. Merritt

Attachments:
References
Figures 1, 2, 3

BELLCOMM, INC.

REFERENCES

1. "Lunar Landing Mission GSOP, Preliminary Section 5, LGC", MIT Instrumentation Laboratory, June 1967.

2. Merritt, A. C., "LM-Earth S-Band Communications for Powered Descent and Ascent Phases of the Lunar Mission", Bellcomm, TM-67-2013-3, May 15, 1967.

NOTE: $+X_B$ IS THE DIRECTION OF THE LM THRUST VECTOR
$+Z_B$ IS IN THE FORWARD LM DIRECTION
$+Y_B$ IS OUT THE RIGHT-HAND-SIDE OF THE LM

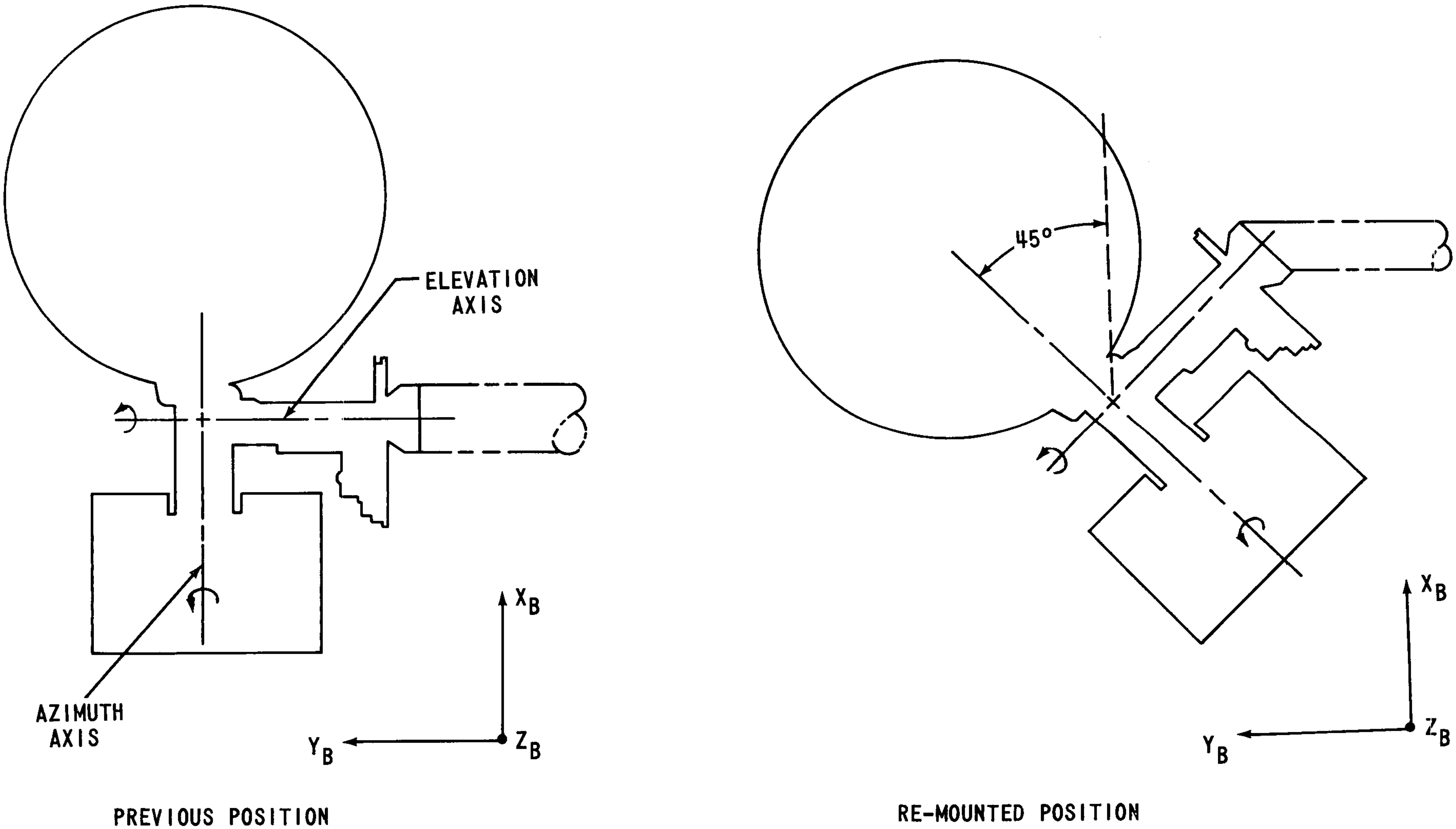

FIGURE I RE-MOUNTING OF LM S-BAND STEERABLE ANTENNA

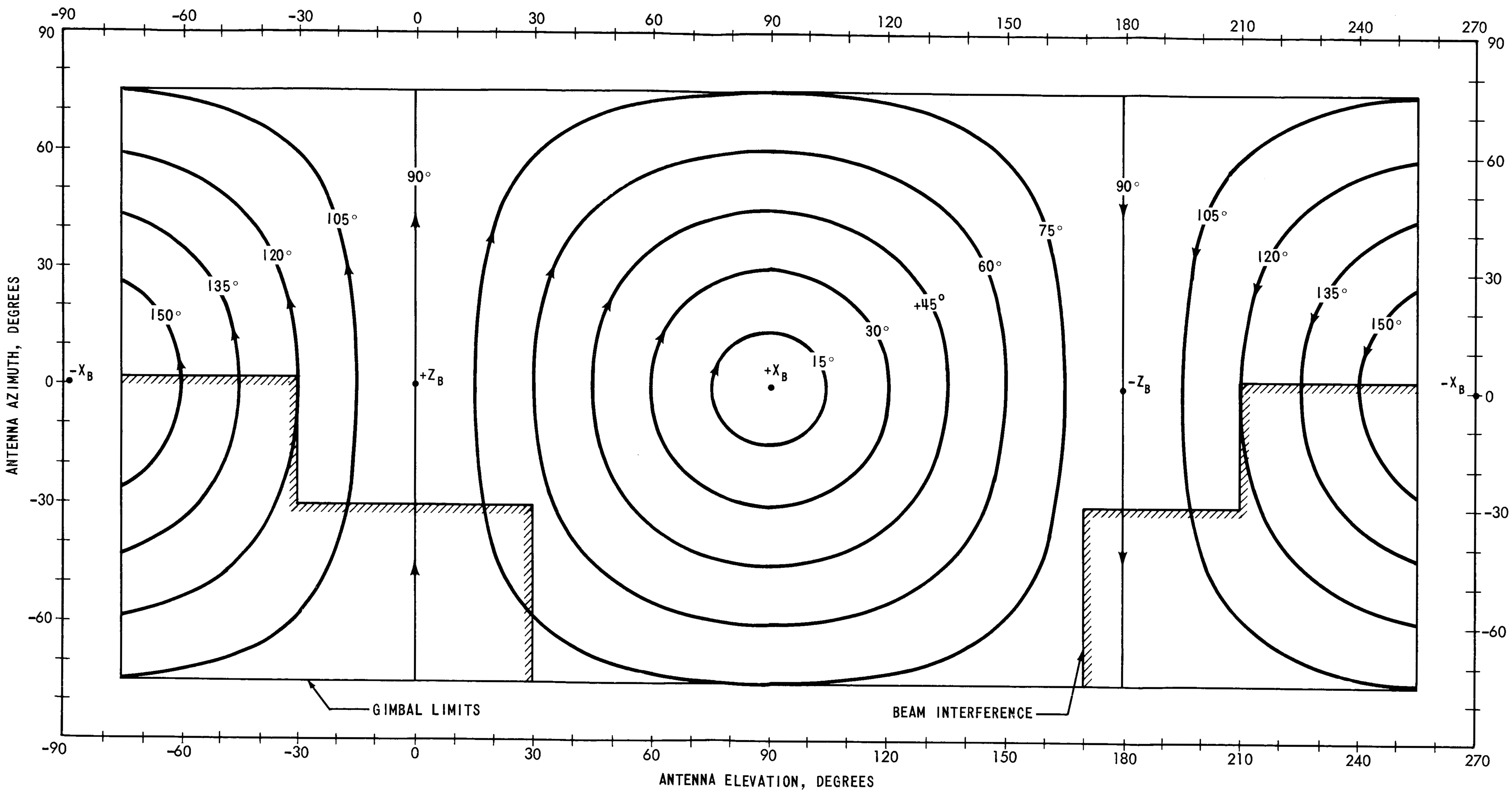

FIGURE 2 - 360° YAW CURVES FOR OLD ANTENNA MOUNTING

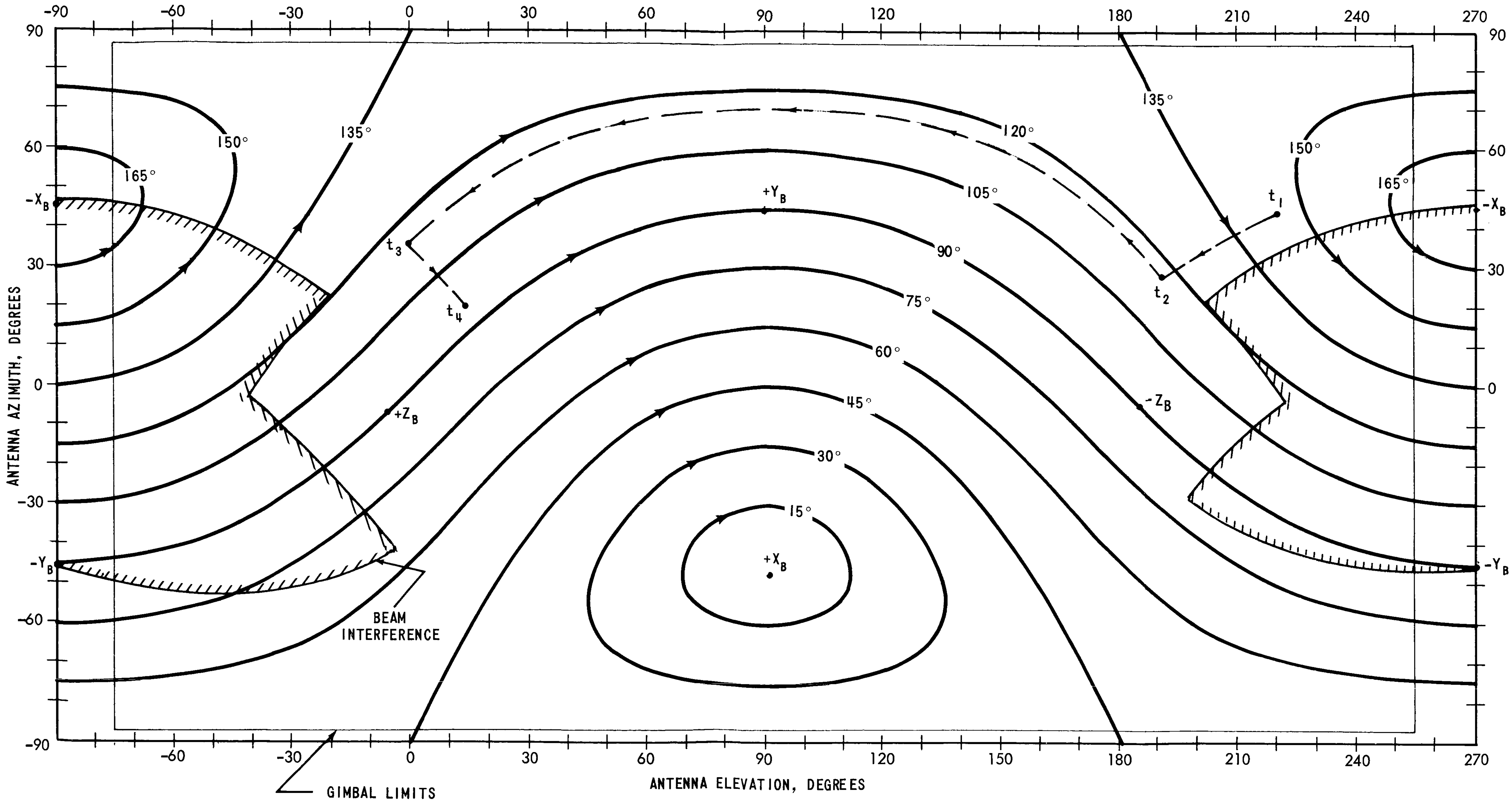

FIGURE 3 - 360° YAW CURVES FOR NEW ANTENNA MOUNTING

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